

On 750 GeV Diphoton Resonance in Stringy Standard-Like Models

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Abstract

The LHC diphoton excess 750 GeV is discussed in a string-inspired standard-like model. Precisely, a singlet scalar-extended SM from a vacua of four stacks of intersecting D6-branes giving rise to a large gauge symmetry is considered. Besides its relevant couplings to the SM sector, the involved scales allow for a scalar mass near to the reported diphoton excess.

Key words: LHC, Standard Model, String Theory.

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1 Introduction

Recently, ATLAS and CMS collaborations have reported an excess of diphotons associated with 750 GeV from LHC Run-II with pp collisions at 13 TeV [1, 2]. This event has received a big interest using different methods and approaches including analytical and simulating ones providing possible physical interpretations. More precisely, several interpretations have been proposed based on extensions of the standard model physics (SM)[3, 4, 5, 6, 7, 8, 9, 10, 11]. One of the most important aims of the investigation is to propose the existence of spinless singlet particles coupled to SM fields. Indeed, the obtained resonance could be interpreted as a scalar field S having a mass around 750 GeV . The process for producing two photons are mostly generated by two possible ways involving the fusion of either the gluons $gg \rightarrow S \rightarrow \gamma\gamma$ or the quarks $qq \rightarrow S \rightarrow \gamma\gamma$. The couplings of such a scalar could be effectively described by the terms $\zeta \supset (S/\Lambda) \left(G_{\mu\nu}^a G^{a\mu\nu} + F_{\mu\nu} F^{\mu\nu} \right)$, where $F_{\mu\nu}$ and $G_{\mu\nu}$ are the strong and electromagnetic fields respectively, giving predictions on the corresponding excess and possible production channels.

In string theory, it has been suggested that effective field theory models can be explored to give a possible interpretation of this new physics [12, 13, 14, 15, 16, 17]. This suggestion has been supported by the fact that the important particle physics ingredients can be embedded in intersecting D-brane models built from the orientifold compactifications of type II superstring models. In this scenario, the gauge groups arise from stacks of D-branes that fill 4D spacetime and wrap appropriate cycles in the Calabi-Yau 3-folds. However, the matter fields live at the intersection of two different D-brane stacks in such a compactification associated with intersection numbers which are subject to restrictions of additional global $U(1)$'s exhibited by the orientifold compactification. In this sens, the stringy effects, which generate corrections to the superpotential by inducing missing couplings relevant for fermion masses, provide an acceptable effective low-energy description for standard-like models or some extensions [18, 19, 20, 21, 22, 23]. Such models usually are pictured as intersecting lines, encoding the gauge symmetry and matter content. These graphs allow for the exploration of several physical effects without the need of a string defined model. Concretely, the possible interaction coupling terms can be derived by examining quantum numbers associated with these brane pictures. Such a method offers a rich discussion in string phenomenology and it can bring new feature on the corresponding physics from higher dimensional supergravity theories[24, 25, 26, 27, 28].

This paper aims to contribute to this issue by addressing the observed 750 GeV diphoton excess in a stringy scalar-extended SM based on intersecting D-brane models. Concretely, we consider a gauge theory based on a vacua of four stacks of intersecting D6-branes wrapping 3-cycles on the orientifold compactification with $U(3) \times Sp(1) \times U(1) \times U(1)$ gauge symmetry.

In this standard-like model, a singlet scalar S is introduced to generate, together with the standard Higgs doublet H , the SM particle masses. The VEV $\langle S \rangle$ and the mass scales m_s of the involved new scalar offer a possible interpretation of the diphoton excess at 750 GeV according to the known data.

The paper is organized as follows. In section 2, we build a gauge theory based on a vacua of four stacks of intersecting D6-branes wrapping 3-cycles on the orientifold compactification with $U(3) \times Sp(1) \times U(1) \times U(1)$ gauge symmetry. In section 3, we present a possible interpretation of the diphoton excess at 750 GeV in a singlet extension of the SM. In section 4, we approach the involved high scales and probe the 750 GeV resonance in terms of the new scalar mass m_s . The last section is devoted to concluding remarks.

2 D6-brane standard-like model

Given that the recently LHC reported diphoton excess corresponds to a heavy mass of 750 GeV and that likely related to a new scalar beyond the SM, we assume that this high resonance has a stringy origin from of a low-scale $M_s \ll M_{Planck}$ effect, and it is a singlet scalar under the SM gauge group. We thus build a stringy model based on four stacks of D6-branes with a flavor symmetry distinguishing various quarks from each others. In this brane building, the gauge symmetry is

$$U(3)_a \times Sp(1)_b \times U(1)_c \times U(1)_d, \quad (1)$$

where the $Sp(1) \simeq SU(2)$ weak symmetry arises from D6-wrapped on an orientifold invariant three-cycle ($b = b^*$). It has been shown that there is no difference between the quark doublets since they have all the same $U(1)_{a,c,d}$ charges. A close inspection shows that one should consider a D6-brane configuration obtained from the compactification of type IIA superstring on $\Pi_{i=1}^3 T_i^2$. The intersection numbers can be obtained from the wrapping numbers of the D6-branes around the T^2 factors. An appropriate choice of such numbers gives the following intersections

<i>Sector</i>	ab	ac	ac^*	ad	ad^*	db	dc^*
<i>Intersection</i>	3	-2	-1	-1	-2	3	-3

Table 1: An intersection numbers of the SM spectrum. The other ones are set to zero.

The field content and the corresponding charges are illustrated in the table 1. In this construction, the three left-handed quarks q^i are localized at intersections of D6-branes a and b while right-handed quarks, \bar{u}^i and \bar{d}^i split into two up quarks $\bar{u}^{2,3}$ and one down quark \bar{d}^3

Sector	ab	ac	ac^*	ad	ad^*	db	dc^*	bc
Fields	q^i	$\bar{u}^{2,3}$	\bar{d}^3	\bar{u}^1	$\bar{d}^{1,2}$	ℓ^i	\bar{e}^i	H
Rep	$3(3, \bar{2})$	$2(\bar{3}, 1)$	$1(\bar{3}, 1)$	$1(\bar{3}, 1)$	$2(\bar{3}, 1)$	$3(1, \bar{2})$	$3(1, 1)$	$1(1, 2)$
Q_a	1	-1	-1	-1	-1	0	0	0
Q_c	0	1	-1	0	0	0	-1	1
Q_d	0	0	0	1	-1	1	-1	0
Y	1/6	-2/3	1/3	-2/3	1/3	-1/2	1	-1/2

Table 2: SM spectrum and their $U(1)_{a,c,d}$ charges for $Y = \frac{1}{6}Q_a - \frac{1}{2}Q_c - \frac{1}{2}Q_d$. The index $i = 1, 2, 3$ is the family index.

which are localized at intersection of the D6-branes a and c/c^* . Two down quarks $\bar{d}^{1,2}$ and one up quark \bar{u}^1 are placed at intersection of the D6-branes a and d/d^* . The three left-handed leptons ℓ^i arise at the intersection of branes b and $d/c, c^*$ respectively. Moreover, the three right-handed electrons \bar{e}^i arise at the intersection of D6-branes d and c^* . Finally, the Higgs doublet H arises at the intersection of D6-branes b and c/c^* . The origin of the matter fields is associated with the linear combination of $U(1)_{a,c,d}$ reproducing the SM particle hypercharges.

The corresponding model can be illustrated in figure 1.

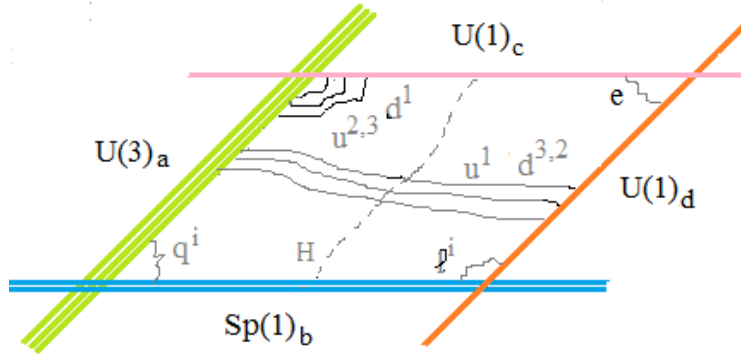


Figure 1: Four-Stack Stringy SM. Bold lines denote D6-branes and thin lines denote chiral and scalar spectrum.

The 4D Yukawa coupling terms can be derived with respect to the symmetry charges proposed in table 1. In fact, the $U(1)_{a,c,d}$ field charges can be used to write down the possible Yukawa couplings interaction terms for the heavy quarks and leptons. These terms are

$$\begin{aligned}
\mathbf{Q}_{c,d} \left(H^\dagger q \bar{c} \right) &= Q_{c,d} (H) + Q_{c,d} (q) = Q_{c,d} (\bar{c}) = 0, \\
\mathbf{Q}_{c,d} \left(H^\dagger q \bar{t} \right) &= 0, \\
\mathbf{Q}_{c,d} \left(H q \bar{b} \right) &= 0, \\
\mathbf{Q}_{c,d} \left(H \ell^i \bar{e}^i \right) &= 0.
\end{aligned} \tag{2}$$

The corresponding Lagrangian is then

$$\zeta_{Yuk} = y_c H^\dagger q \bar{c} + y_t H^\dagger q \bar{t} + y_b H q \bar{b} + y_{e^i} H \ell^i \bar{e}^i, \tag{3}$$

where $y's \leq 1$ are coupling constants accounting for the Higgs-fermion interaction strenghts between these terms.

3 Singlet scalar-extension

It turns out that the remaining phenomenologically desired coupling terms can be implemented by U(1)'s charged scalars extendeding the SM [24, 25, 26]. In type IIA superstring theory, a scalar can be obtained from either the geometric deformation or the stringy deformation associated with NS-NS and R-R fieldd on cycles of internal manifolds. In what follows, we add a siglet complex scalar field S obtained by combining a complex structure deformation and the R-R 3-form wrapping a 3-cycle in the internal space. The reason for adding such a scalar is to generate missing coupling terms with respect to U(1) charges. The new scalar must have the charges,

<i>Sector</i>	<i>Field</i>	<i>Rep</i>	Q_a	Q_c	Q_d	Y
cd	S	$1(1,1)$	0	1	-1	0

Table 3: Required extra singlet with its $U(1)_{c,d}$ charges.

This is shown in the figure 2.

With this scalar adding, the absent terms are now generated via higher order terms and thus will be suppressed by factors $\langle S \rangle^n / M_s^m$, where n and m are power integer numbers, M_s denotes the string mass and $\langle S \rangle$ its VEV. These terms are now

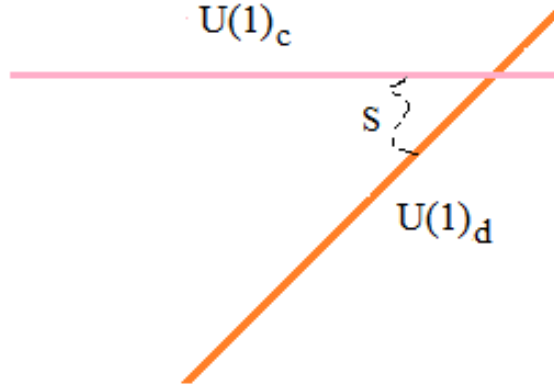


Figure 2: New scalar and its associated $U(1)_{c,d}$ charges indicated by the dotted thin line.

$$\begin{aligned}
\mathbf{Q}_{c,d} (SH^\dagger q\bar{u}) &= Q_{c,d} (S) + Q_{c,d} (H) + Q_{c,d} (q) = Q_{c,d} (\bar{u}) = 0, \\
\mathbf{Q}_{c,d} (S^* Hq\bar{d}) &= 0, \\
\mathbf{Q}_{c,d} (S^* Hq\bar{s}) &= 0, \\
\mathbf{Q}_{c,d} (S^2 (H\ell^i)^2) &= 0.
\end{aligned} \tag{4}$$

The corresponding Lagrangian is then

$$\begin{aligned}
\zeta'_{Yuk} &= M_s^{-1} (y_u SH^\dagger q\bar{u} + y_d S^* Hq\bar{d} + y_s S^* Hq\bar{s}) \\
&\quad + M_s^{-3} y_{\nu^i} S^2 (H\ell^i)^2.
\end{aligned} \tag{5}$$

In this model, the VEV $\langle S \rangle$ induces the perturbatively missing Yukawa couplings and along with the Higgs VEV the masses for these light fermions (5). Compared to the previous contributions given in (3), they are suppressed by the string mass scale M_s with a high suppression for the left-handed neutrino terms.

4 Probe of the 750 GeV mass

Without requiring geometric specifics of the defined stringy model, more results beyond the interaction terms could be derived. Particulary, it includes the involved string scale M_s with the VEV $\langle S \rangle$ and mass m_s of the scalar field S . For that, after the electroweak symmetry breaking by the Higgs VEV at $\langle H \rangle \simeq 246 \text{ GeV}$, adequate combinations of fermion masses, for which their net scalar-fermion couplings could be absorbed, can give approximate values of the new scales. Indeed, using the left-handed neutrino mass terms appearing in (5) with

an upper bound of $m_{\nu_\tau} \lesssim 1 \text{ eV}$, we can predict the string scale M_s as

$$M_s = \frac{y_{\nu_\tau}}{y_u^2} \frac{m_u^2}{m_\nu} \sim 10^4 \text{ GeV}, \quad (6)$$

and then the scalar VEV $\langle S \rangle$ becomes

$$\langle S \rangle = \frac{y_c}{y_s} M_s \frac{m_s}{m_c} \sim 10^3 \text{ GeV}. \quad (7)$$

At this point, it is worth mentioning that we have two new high scales: one belongs to the low-string scale M_s (6), and the other belongs to the VEV of the new scalar $\langle S \rangle$ given in eq.(7). Other than the partial explanation of the fermion mass hierarchies and the smallness of neutrino masses, these net scales allow for the possibility to wonder if the recent 750 GeV resonance is somehow related to such low-scale stringy effect. In fact, we can go further and calculate the mass of the new scalar S . The latter is proportional to the scalar VEV given in eq.(7) through its self-coupling parameter $\lambda_{s-s} \leq 1$ such as

$$m_S = \sqrt{\lambda_{s-s}} \langle S \rangle \leq 10^3 \text{ GeV}, \quad (8)$$

where we see clearly that for the scalar self-coupling value $\lambda_{s-s} \simeq 0,562$, one can get a mass of $m_S \simeq m_{\gamma\gamma} = 750 \text{ GeV}$ corresponding to the reported LHC diphoton excess. These new scales that result is a stringy prediction for physics beyond SM push to ask whether the present LHC Run II at $\sqrt{s} = 13 \text{ TeV}$ is able to see more significant stringy physics directly.

5 Conclusion and related remarks

In this work, we have discussed the LHC diphoton excess at 750 GeV in a string-inspired gauge theory where the corresponding effective low-energy theory emerges from type IIA superstring on the orientifold compactification. Concretely, we have considered four stacks of intersecting D6-branes configuration producing the SM spectrum extended by a singlet scalar S . The corresponding effective superpotential produces different coupling scales relative to allowed perturbative and higher order suppressed terms. Attributing the allowed perturbative terms to the known heavy quarks and leptons and the higher order generated terms to known light quarks and neutrinos, the hierarchy of fermion masses find an explanation through higher order terms suppressed by factors $\langle S \rangle^n / M_s^m$. We have further probed the stringy explanation of LHC 750 GeV diphoton excess by probing the new scales involved in the model, low-string scale $M_s \sim 10^4 \text{ GeV}$ and the scalar VEV $\langle S \rangle \sim 10^3 \text{ GeV}$, by referring to known data and then we have shown how the new scalar can have a mass of the detected

diphoton excess $m_S \simeq m_{\gamma\gamma} = 750 \text{ GeV}$.

Alternatively gauge theories can be geometrically engineered from singularities of the K3 surface [29]. A way to get such gauge theories from type IIA superstring is to consider a compactification on a singular 3-fold with K3 surface fibration over a base space B. In this way, the gauge symmetry and matter fields are obtained from the singularities of the fiber and the non-trivial geometry of the base space, respectively. In connection with the model presented here, it is possible to consider an SU(7) singularity in the K3 fiber. Thus, the deformation of such a singularity could produce the following decomposition $SU(7) \rightarrow SU(3) \times SU(2) \times U(1) \times U(1)$ gauge symmetry. It would also be interesting to explore the geometric engineering method based on string compactifications on singular manifolds. We hope to report elsewhere on this possible connection.

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